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Utilization of Lightweight Materials Made From Coal Gasification Slags

Quarterly Report
December 1, 1997 - February 28, 1998

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For
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1.0 PROJECT OBJECTIVES, SCOPE AND DESCRIPTION OF TASKS

1.1 Introduction

The integrated-gasification combined-cycle (IGCC) process is an emerging technology that utilizes coal for power generation and production of chemical feedstocks. However, the process generates large amounts of solid waste, consisting of vitrified ash (slag) and some unconverted carbon. In previous projects, Praxis investigated the utilization of "as-generated" slags for a wide variety of applications in road construction, cement and concrete production, agricultural applications, and as a landfill material. From these studies, we found that it would be extremely difficult for "as-generated" slag to find large-scale acceptance in the marketplace even at no cost because the materials it could replace were abundantly available at very low cost. It was further determined that the unconverted carbon, or char, in the slag is detrimental to its utilization as sand or fine aggregate. It became apparent that a more promising approach would be to develop a variety of value-added products from slag that meet specific industry requirements. This approach was made feasible by the discovery that slag undergoes expansion and forms a lightweight material when subjected to controlled heating in a kiln at temperatures between 1400 and 1700°F. These results confirmed the potential for using expanded slag as a substitute for conventional lightweight aggregates (LWA). The technology to produce lightweight and ultra-lightweight aggregates (ULWA) from slag was subsequently developed by Praxis with funding from the Electric Power Research Institute (EPRI), Illinois Clean Coal Institute (ICCI), and internal resources.

The major objectives of the subject project are to demonstrate the technical and economic viability of commercial production of LWA and ULWA from slag and to test the suitability of these aggregates for various applications. The project goals are to be accomplished in two phases: Phase I, comprising the production of LWA and ULWA from slag at the large pilot scale, and Phase II, which involves commercial evaluation of these aggregates in a number of applications.

Primary funding for the project is provided by DOE's Federal Energy Technology Center (FETC) at Morgantown, with significant cost sharing by Electric Power Research Institute (EPRI) and Illinois Clean Coal Institute (ICCI).

1.2 Scope of Work

The Phase I scope consisted of collecting a 20-ton sample of slag (primary slag), processing it for char removal, and pyroprocessing it to produce expanded slag aggregates of various size gradations and unit weights, ranging from 12 to 50 lb/ft^3. In Phase II, the expanded slag aggregates are being tested for their suitability in manufacturing precast concrete products (e.g., masonry blocks and roof tiles) and insulating concrete, first at the laboratory scale and subsequently in commercial manufacturing plants. These products will be evaluated using ASTM and industry test methods. Technical data generated during production and testing of the products will be used to assess the overall technical viability of expanded slag production. Relevant cost data for physical and pyroprocessing of slag to produce expanded slag aggregates will be gathered for comparison with (i) the management and disposal costs for slag or similar wastes and (ii) production costs for conventional materials which the slag aggregates would replace. In addition, a market assessment will be made to evaluate the economic viability of these utilization technologies.

1.3 Phase I Task Description

A summary of the tasks performed in Phase I is given below:

Task 1.1 **Laboratory and Economic Analysis Plan Development**: Development of a detailed work plan for Phase I and an outline of the Phase II work.

Task 1.2 **Production of Lightweight Aggregates from Slag**: This task covered selection and procurement of project slag samples, slag preparation including screening and char removal, and slag expansion in a direct-fired kiln and fluid bed expander. The char recovered from the slag preparation operation was evaluated for use as a kiln fuel and gasifier feed. Environmental data for slag-based lightweight aggregate (SLA) production was collected.

Task 1.3 **Data Analysis of Slag Preparation and Expansion**: Analysis and interpretation of project data, including development of material and energy balances for slag processing and product evaluation.

Task 1.4 **Economic Analysis of Expanded Slag Production**: Economic analysis of the utilization of expanded slag was conducted by determining production costs for slag-based LWAs and ULWAs. Expanded slag production costs were compared with the market value of similar products both with and without taking into account the avoided costs of disposal and with the costs of management of slag as a solid waste.

Task 1.5 **Topical and Other Reports**: Preparation topical, financial status, and technical progress reports in accordance with the Statement of Work.

1.4 Phase II Task Description

A summary of the tasks to be performed in Phase II is given below.

Task 2.1 **Test Plan for Applications of Expanded Slags (Field Studies)**: This task involves the development of selection criteria and a field test plan for applications of expanded slag. This plan will serve as a guide in the selection and implementation of field demonstrations for the most promising expanded slag utilization applications. Field applications will be selected on the basis of laboratory results, the marketability of the products, and the suitability of the project slags for producing them. The following applications are under consideration for testing:

- Lightweight concrete blocks made from 50 lb/ft^3 SLA
- Lightweight roof tiles made from 40 lb/ft^3 SLA
- Loose fill insulation made from 16 lb/ft^3 SLA
- Lightweight insulating concrete made from 16 lb/ft^3 SLA

Task 2.2 **Field Studies to Test Expanded Slag Utilization**: Under this task, field testing of the applications identified in Phase II, Task 2.1, will begin with test work to optimize the concrete mixes made from expanded slag.

Task 2.3 **Data Analysis of Commercial Utilization of Expanded Slags:** The objective of this task is to assimilate the data and test results collected during Phase II, Task 2.2, convert these findings to common engineering terms, and correlate these results with comparable information for conventional lightweight aggregates as reported in the literature. The data analysis will provide specific answers to the following issues:

- Performance of expanded slag compared with that of conventional materials
- Technical viability of lightweight and ultra-lightweight slags as aggregates.

Task 2.4 **Economic Analysis of Expanded Slag Utilization:** The objective of this task is to expand upon the preliminary economic assessment of expanded slag utilization conducted during Phase I. The economics will be studied based on the production costs for SLA in comparison with current market prices for conventional materials. During the Phase I preliminary evaluation, two production scenarios emerged:

- Production of SLA at the gasifier location (on-site production)
- Production of SLA at a lightweight aggregate facility (off-site production).

The impact of the avoided costs of slag disposal on the economics of SLA production will also be evaluated. Slag utilization data and product samples will be made available to commercial lightweight aggregate users for validation of estimated market prices. The impact of SLA market prices on the economics of SLA production will also be studied.

Task 2.5 **Final Report:** The data generated and collected during the project will be compiled in a final report to be submitted at the end of the project that will be a comprehensive description of the results achieved, consistent with the Reporting Requirements. Data from topical and field reports will be summarized. The report will include the original hypothesis of the project and present the investigative approaches used, complete with problems encountered or departures from the planned methodology, and an assessment of their impact on the project results.

1.5 Scope of This Document

This is the fourteenth quarterly report and summarizes the work undertaken during the performance period between 1 December 1997 and 28 February 1998. It is the seventh quarterly report for Phase II. This document summarizes the Phase II accomplishments to date along with the major accomplishments from Phase I.

2.0 SUMMARY OF WORK DONE DURING THIS REPORTING PERIOD

2.1 Summary of Major Accomplishments

In the current reporting period, test work focused on Slag III lightweight aggregates. The following was accomplished during this reporting period:

1. Testing of expanded Slag III for the lightweight block application was completed satisfactorily.

2. Testing of expanded Slag III made from 50/50 Slag III/clay for the roof tile application was completed satisfactorily. Specimens with a strength of over 5,600 psi were produced.

3. The second phase of laboratory testing and evaluation of expanded Slag III for use in making cement concrete waterproof panels was completed satisfactorily. The user has expressed interest in buying the material.

2.2 Chronological Listing of Significant Events in This Quarter

The following significant events occurred during the current reporting period:

Date	Description
1/20/98	Testing and evaluation of expanded Slag III for block application initiated
2/2/98	Rooftile evaluation of expanded slag/clay 50/50 blends was initiated
2/15/98	Testing and evaluation of expanded Slag III in panel application completed by end user

3.0 TO DATE ACCOMPLISHMENTS

A summary of the work completed in Phase I is given below.

Date	Phase I Accomplishments Description
10/24/94	Draft Laboratory and Economic Analysis Plan (project work plan) submitted
11/18/94	Slag char removal completed on the advance sample and prepared slag laboratory expansion testing initiated
12/02/94	Final "Laboratory and Economic Analysis Plan" prepared and submitted
05/21/95	Primary slag sample (20 ton) received at Penn State for preparation
06/01/95	Pilot unit for char removal set up and processing work started
08/20/95	Primary slag sample processing for char removal completed
9/10/95	Laboratory expansion studies of slag and slag/clay blends started
10/15/95	1-ft and 3-ft diameter kilns commissioned for pilot testing
11/15/95	Pilot testing of Slag I and Slag II and pellets in 3-ft dia. direct-fired kiln completed
11/17/95	Pilot testing using fluidized bed expander completed
12/12/95	SLA product characterization initiated
1/20/96	Laboratories for testing of SLA products identified
2/16/96	Test plan for second batch of fluid bed expander testing at Fuller completed

A summary of the work completed in Phase II to date is given below.

Date	Phase II Accomplishments Description
4/30/96	Application for continuation of the project to Phase II submitted
5/31/96	Phase I Final Report (draft) submitted to METC
7/1/96	Phase I Topical Report (final version) submitted
7/14/96	Approval for continuation of the project to Phase II was received from METC
7/14/96	Structural concrete laboratory tests started
7/15/96	Lab testing of SLA for roof tile and insulating concrete applications completed
7/15/96	Evaluation of SLA for completed
7/30/96	Evaluation of SLA for loose fill insulation completed
10/10/96	Mix designs for block production selected
11/10/96	Laboratory evaluation of the Slag II completed
10/30/96	Structural concrete laboratory tests completed
11/10/96	Laboratory evaluation of Slag III for LWA production completed
1/10/97	Laboratory testing of SLA for structural concrete application completed
2/19/97	First batch of laboratory tests of selected block mixes completed
4/30/97	Processing of Slag III for char removal completed
5/20/97	Preparatory work for Slag III pyroprocessing completed
7/30/97	Preparation of Slag III for SLA production completed
8/20/97	Utilization of SLA as growing medium for potted plants completed successfully
10/2/97	Exploratory testing of expanded slag for nursery applications completed
10/2/97	Laboratory testing of expanded Slag I for block application completed
11/1/97	Testing of expanded slag in panel application completed
12/2/97	Second phase of testing of expanded slag for nursery applications started
1/20/98	Evaluation of expanded Slag III for block and roof tile applications initiated
2/15/98	Second round evaluation of expanded Slag III in panel application completed by end user

4.0 TECHNICAL PROGRESS REPORT

4.1 Laboratory Evaluation of Expanded Slag III for Testing of Masonry Blocks

The SLA produced from Slag III was tested by making concrete for lightweight blocks in order to verify the utilization applications developed for the other slags. Test mixes were formulated based on the experience with the work done using Slag I, with the objective of manufacturing two types of blocks:

- Regular-weight blocks with a dry weight of approximately 33.5 lb (150 lb/ft^3 concrete)
- Lightweight blocks with a dry weight of approximately 27 lb (115 lb/ft^3 concrete)

For both block mixes, the conventional lightweight aggregate was replaced by fine SLA III made from a 10 x 50M Slag III feed (SLA III-F). The cement-to-aggregate ratio used was identical to that currently used at the block manufacturing plant. Test specimens (2" diameter, 3.5" tall cylinders) were made from the concrete and stored in a steam chamber. A total of three specimens was made for each batch. The compressive strength was measured after 7 and 28 days of curing, and the average values are reported in Table 1.

As may be seen in Table 1, the unit weights of the specimens (Tests LB1-LB6) made with SLA III were lower than the maximum desirable weight of 115 lb/ft^3. However, except for Test LB6, their compressive strengths were considerably higher than the 1000 psi required for above-grade blocks, but short of the 2000-psi strength required for below-grade blocks. Since this is the first batch of tests using SLA III, it is anticipated that a higher strength can be achieved by adjusting the mix design.

Table 1. Results of Batch Mix Tests Conducted for Masonry Blocks Using SLA

Test No.	Materials Used by Volume, ml					Concrete		
	Sand		SLA-Iii(F) 10x50M slag	Total Aggr.	Cement	Unit Weight lb/ft^3	Strength, psi	
	Washed	Unwashed					7-day	28-day
Unit wt, lb/ft^3	106.6	103.9	41.0		94.0	-	-	-
Cement-to-aggregate ratio = 1:7.73 by volume								
LB1	1978	–	1616	3594	465	114.6	1225	1380
Cement-to-aggregate ratio = 1:8.66 by volume								
LB2	–	2344	1683	4027	465	117.9	1012	1029
Cement-to-aggregate ratio = 1:6.74 by volume								
LB3	–	2344	1683	4027	598	108.7	930	1102
Cement-to-aggregate ratio = 1:7.46 by volume								
LB4	–	2783	1683	4466	598	115.9	1309	1575
Cement-to-aggregate ratio = 1:7.46 by volume								
LB5	–	2930	1530	4460	598	114.2	924	1273
Cement-to-aggregate ratio = 1:9.59 by volume								
LB6	–	2930	1530	4460	465	108.2	423	689
Mix 30S (cement-to-aggregate ratio = 1:8.22 by volume)								
Aggr. Mix	55% (LSS)	21% (SS)	24%	100%			-	-
82797-1 SLA I (F)	1650 LSS	630 SS	720	3000	346	110.1	-	1558
Lightweight Block Mix No. 19S (cement-to-aggregate ratio = 1:5.97 by volume)								
82797-3 SLA I (F)	1290	-	1710	3000	453	86.8	-	1402

Three tests were also compared with results for SLA I (mix designs 30S and 19S) obtained at Harvey Cement. The regular block mix using SLA I (F) (Test 21997-1) had a 28-day compressive strength of 1558 psi, while one made using SLA I (C) had a strength of 1402 psi (Test 82797-3). The unit weight of the concrete was considerably lower than the typical value required for regular blocks.Tests with lightweight block Mix 19S resulted in compressive strengths of 1090-1402 psi, which is consistent with the low unit weight of the concrete (78.6-86.5 lb/ft^3).

It is possible to further increase the strength of the SLA concrete by adding some fine sand to compensate for the lack of fines in the slag. This will be considered in the next batch of tests.

A section of the test specimens (Test LB1) was made and photographed to determine the uniformity of the matrix. As may be seen in Figure 1, the texture appears to be uniform, indicating the good quality of the mix.

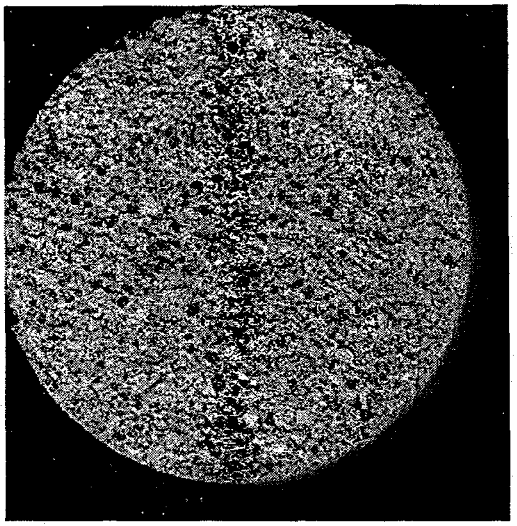
4.2 Laboratory Evaluation of SLA III for Roof Tile Application

The objective of this test program was to produce lightweight concrete suitable for the roof tile application from SLA III using a 50/50 ratio of Slag III and clay. The compressive strength requirements for this application are in the 2500-4000 psi range, with corresponding unit weights in the 115-105 lb/ft^3 range. Previous evaluations have been conducted for this application using two different aggregates: (i) expanded slag (SLA I) and (ii) expanded slag I/clay (50/50) mixture, which were compared with an expanded clay product sample provided by a commercial roof tile manufacturer. The compressive strengths the resulting specimens from both of these mixes were below the ASTM requirements. The objective of the current batch of testing was to evaluate the potential for using SLA III for the roof tile application.

The expanded slag aggregates used in the test program were made from a 50/50 blend of Slag III/clay which was crushed to match the size distribution of the LWA aggregates used by the roof tile manufacturer. The tests were performed using SLA III/clay in a saturated surface dry (SSD) condition as defined by ASTM. The moisture content of the aggregates was measured and recorded. Typically, a roof tile mix uses a cement-to-aggregate ratio of 1:2.5, along with various additives such as accelerators and superplasticizers. Because the specific mix formulations used by roof tile manufacturers are considered proprietary information, commonly available accelerators (calcium chloride dihydrate ($CaCl_2 \bullet 2H_2O$) and sodium silicate) and a common commercial superplasticizer (commercially known as Mighty 150) were evaluated at levels consistent with industry practice. Both the accelerator and the superplasticizer were used in the earlier tests, while in the current batch of tests (RT-1 and RT-2) only the superplasticizer was used.

Three 2" x 2" x 2" mortar cubes were cast using the concrete, cured in a wet box (relative humidity of ~70%) for 2 hours, and then steam-cured at ~60°C for 4 hours. The cubes were demolded and returned to the wet box for further curing to 7 days. The cubes were then weighed and broken in compression. A summary of the formulations and 7-day compressive strengths is presented in Table 2. The highest 7-day compressive strength for the SLA III specimens was 5600 psi, which is considerably higher than the previous best results of 2800 psi for SLA I and exceeds the ASTM requirement of 4000 psi. One reason for these good results is that the baghouse dust fines were added to the SLA III aggregate and used in the mix. The unit weights of the specimens made from SLA III ranged between 113.6 and 114.6 lb/ft^3.

Actual Size



Enlarged 180%

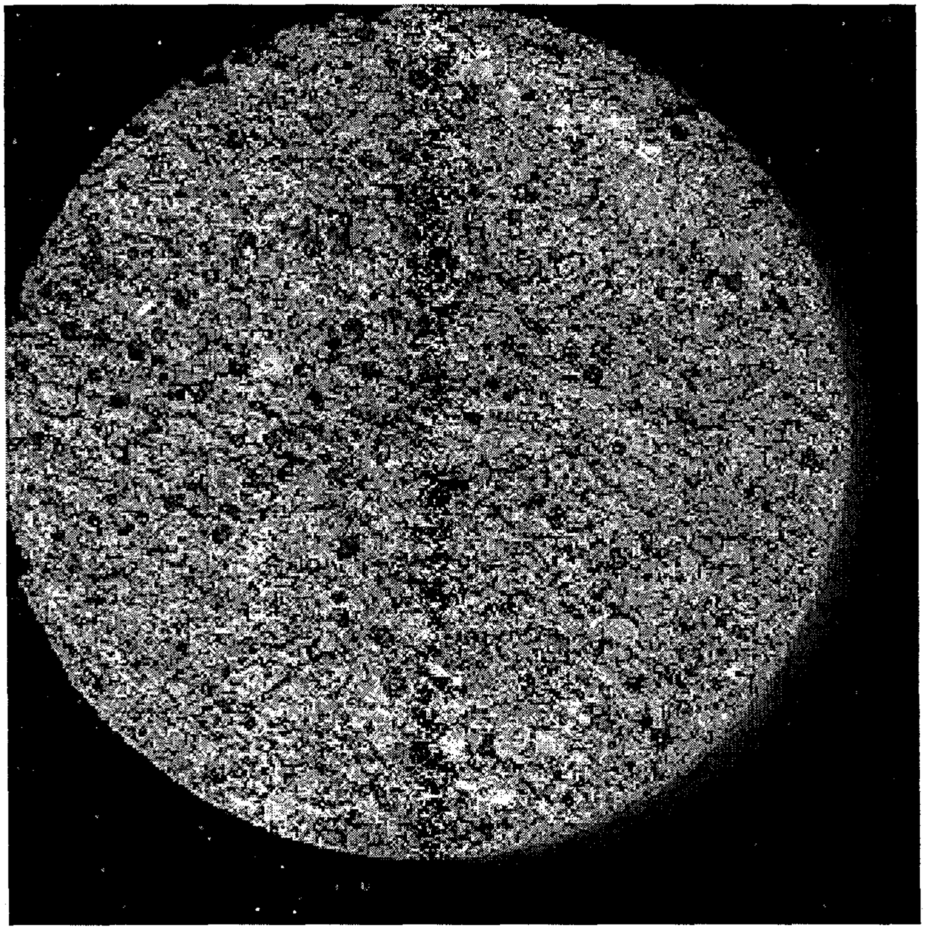


Figure 1. **Cross-Section of Block Concrete Test Specimen (Actual Size and Enlarged)**

Table 2. Evaluation of SLA III as Aggregate in Roof Tile Application*

LWA	SSD M%	$CaCl_2 \bullet H_2O$ (Wt% of cement)	Plasticizer (Wt% of Cement)	Water/ Cement Ratio	LWA/ Cement Ratio	Mortar Unit Wt (lb/ft^3)	Compressive Strength 7-day (psi)
50/50 SLA III Test No RT1	18.1*	-	2	0.57*	2.5	113.6	5598
50/50 SLA III Test No RT2	18.1*	-	2	0.47*	2.5	114.6	5603
SLA I**	18.5	2	2	0.35	2.5	93.3	2806
Commercial LWA**	17.0	2	2	0.45	2.5	105.3	3390
Slag/Clay**	26.0	2	1.5	0.35	2.5	105.2	2303

*SLA was used in "as is" dry form using a higher cement-to-water ratio. However, the SSD moisture and water-to-cement ratios were calculated using another sample and reported for comparison.
** Tests conducted with SLA I and commercial aggregate used by the roof tile manufacturer were done previously.

Some of the cylinders with RT1 and RT2 were allowed to cure further to obtain 28-day compressive strengths. The results are given in Table 3. These results were compared with those for tests conducted using the best conditions selected from the work done with SLA I.

Table 3. 28-Day Results of SLA Tests for Roof Tile Application

Aggregate	W/C	SSD	Unit Weight lb/ft^3	28-Day Compressive Strength, psi
SLA III-RT1	0.75	18.1*	113.6	5603
SLA III-RT2	0.65	18.1*	114.6	6421
Aggregate used at roof tile plant	0.45	16.8	102.2	4789
SLA I	0.35	24.6	94.5	2823
Slag/clay 50/50	0.35	19.6	97.4	2808
Commercial aggregate	0.40	15.1	115.6	7292

*SLA was used in "as is" dry form using a higher cement-to-water ratio. However, the SSD moisture and water-to-cement ratios were calculated using another sample and reported for comparison.

Superplasticizer:	1.5 ml/100 g cement (Mighty 150)
Accelerator:	2% by weight ($CaCl_2 \bullet 2H_2O$)
Aggregate-to-cement ratio (by weight):	2.5
Water-to-cement ratio:	to obtain 0-1 slump

As may be seen in Table 3, the Slag III/clay mix resulted in a compressive strength of 5600-6400 psi, with corresponding unit weights of 114-115 lb/ft^3. This is the first time that such a high strength has been obtained using an expanded slag aggregate. These tests will be repeated to verify their reproducibility.

4.3 Evaluation of SLA in Production of Cement Panels (Waterproof Boards)

Based on evaluation of the results using SLA to make insulating concrete, another similar application was identified: production of lightweight cement concrete panels used in the construction of bathrooms and other areas where walls are exposed to moisture. This is a relatively new but fast growing application that requires 35-45 lb/ft^3 aggregates. Praxis contacted a manufacturer and sent samples of SLA I to them for laboratory evaluation. Exploratory tests indicated that SLA could be used a substitute for conventional lightweight aggregates to make these panels. Currently, Praxis is jointly exploring with them various options for producing SLA at their plant and supplying them with technical information during the project to evaluate the process economics.

5.0 PLAN FOR THE NEXT QUARTER

The following activities are planned for the next quarter:

- Continue laboratory evaluation of SLA I for horticultural applications.
- Conduct laboratory testing and select a mix design for the commercial-scale block-making production run.
- Complete laboratory evaluation of the SLA for concrete panel applications.
- Report the new results of the roof tile application to roof tile manufacturers in order to have them evaluate a large sample of SLA for this application.